GESP-258
NASA-CR-72560

N69-32032

ADVANCED REFRACTORY ALLOY CORROSION LOOP PROGRAM

QUARTERLY PROGRESS REPORT NO. 16
For Quarter Ending April 15, 1969

prepared by
R. W. Harrison

prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research Center
Contract NAS 3-6474
Robert L. Davies, Project Manager
Materials Section

NUCLEAR SYSTEMS PROGRAMS
SPACE SYSTEMS
GENERAL ELECTRIC
CINCINNATI, OHIO 45215

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Period January 15 to April 15, 1969

May 16, 1969

CONTRACT NAS 3-6474

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FOREWORD

The work described herein is sponsored by the National Aeronautics and Space Administration under Contract NAS 3-6474. R. L. Davies of NASA - Lewis Research Center is the NASA Technical Manager.

The program is being administered for the General Electric Company by E. E. Hoffman, and R. W. Harrison is acting as the Program Manager. J. Holowach, the Project Engineer, is responsible for the loop design, facilities procurement, and test operations. Personnel making major contributions to the program during the current reporting period include:

Loop Operation - A. Losekamp, J. Reeves, S. Roof and T. Irwin.

Partial Pressure Gas Analysis - Dr. T. Lyon

ADVANCED REFRACTORY ALLOY CORROSION LOOP PROGRAM

I. INTRODUCTION

This report covers the period from January 15, 1969 to April 15, 1969. The primary task of this program is to fabricate, operate for 10,000 hours and evaluate a T-111 Rankine System Corrosion Test Loop. Materials for evaluation include the containment alloy, T-111 (Ta-8W-2Hf) and the turbine candidate materials Mo-TZC and Cb-132M which are located in the turbine simulator of the two-phase potassium circuit of the system. The loop design will be similar to the Cb-1Zr Rankine System Corrosion Test Loop; a two-phase, forced convection, potassium corrosion test loop which has been tested under Contract NAS 3-2547.[1] Lithium is being heated by direct resistance in a primary loop. Heat rejection for condensation in the secondary potassium loop is being accomplished by radiation in a high vacuum environment to the water cooled chamber. The compatibility of the selected materials will be evaluated at conditions representative of space electric power system operating conditions, namely:

a. Boiling temperature, 2050°F

b. Superheat temperature, 2150°F

c. Condensing temperature, 1400°F

d. Subcooling temperature, 1000°F

e. Mass flow rate, 40 lb/hr

f. Boiler exit vapor velocity, 50 ft/sec

g. Average heat flux in plug (0-18 inches), 240,000 Btu/hr ft^2

h. Average heat flux in boiler (0-250 inches), 23,000 Btu/hr ft^2

In addition to the primary program task cited above the program also includes capsule testing to evaluate advanced tantalum alloys of the ASTAR 811 type (Ta-8W-1Re-1Hf) in both potassium and lithium.

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[1] Hoffman, E. E. and Holowach, J., Cb-1Zr Rankine System Corrosion Test Loop, Potassium Corrosion Test Loop Development Topical Report No. 7, R66SD3016, General Electric Company, Cincinnati, Ohio, May 1, 1968.

Also included in the program is the fabrication, 5000-hour operation and evaluation of a 2600°F, high flow velocity, pumped lithium loop designed to evaluate the compatibility of the ASTAR 811 type alloys, T-111, T-222, and the tungsten alloy, W-25Re-30Mo at conditions simulating an out-of-pile thermionic reactor system.

II. SUMMARY

Testing of the T-111 Rankine System Corrosion Test Loop was initiated on January 25, 1969.

On April 19, 1969 the T-111 Corrosion Loop completed 2000 hours of stable operation without any difficulty.

III. PROGRAM STATUS

A. T-111 RANKINE SYSTEM CORROSION TEST LOOP START-UP

Boiling operation of the corrosion loop was initiated by first increasing the lithium temperature to 1350°F at a flow rate of approximately 2 gpm. The secondary EM pump was adjusted to supply a low flow of potassium to the boiler, and the flow rate and primary temperature were gradually increased at a rate to maintain the chamber pressure below 5×10^{-7} torr. The outgassing rate increased considerably as the loop temperatures were increased, and the titanium sublimation pumps were used to assist the getter-ion vacuum pumps in maintaining a 10^{-7} torr pressure level in the vacuum chamber.

The rate of increase to the test conditions was limited by the outgassing of the loop components. The chamber pressure and the partial pressures of the principal residual gases during this period when the test conditions were being approached is shown in Figure 1. Hydrogen accounted for over 95% of the total residual gas pressure. Although the chamber pressure reached the 10^{-6} torr scale during start-up the partial pressures of oxygen bearing residual gases were 10^{-8} torr or lower. Additional discussion of the partial pressure gas analysis of the test chamber environment is covered later in this report.

Short periods of unstable boiling were noted during the startup of the loop as adjustments to the lithium temperature and potassium flow caused boiling to move out of the plug section. This effect was observed in the operation of the Cb-1Zr Rankine System Corrosion Test Loop and is described in detail in the topical report.[2] The typical effect of these boiling instabilities on the potassium pressure and flow is shown in Figure 2. After a short period of time (approximately 22 minutes) of unstable boiling the potassium EM pump power was decreased with a corresponding decrease in potassium flow and pressure. Boiling returned to the plug section and became stable.

[2] Hoffman, E. E., Holowach, J., Cb-1Zr Rankine System Corrosion Test Loop, Topical Report No. 7 NASA Contract NAS 3-2547, General Electric Company Report R67SD3016.

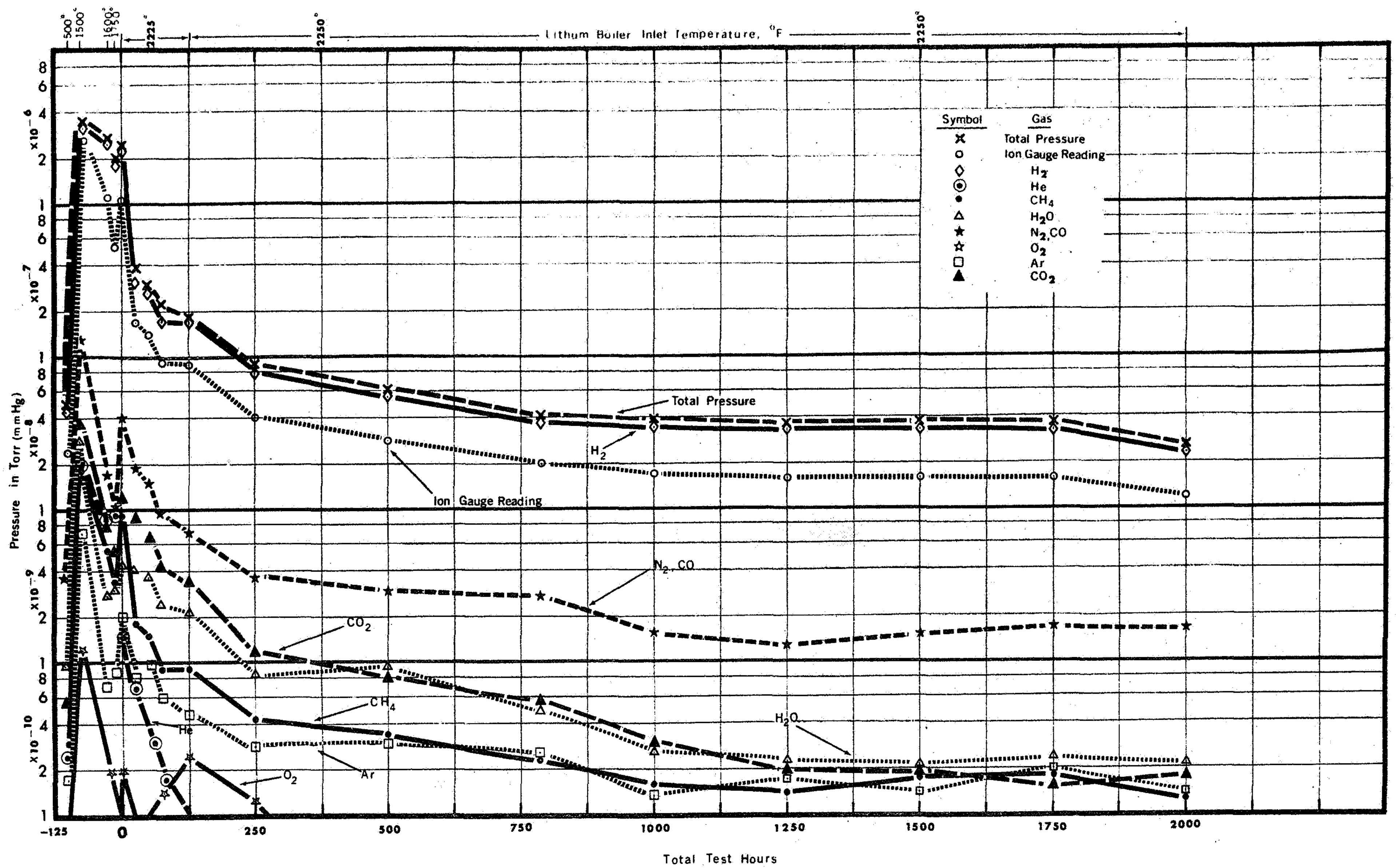

Figure 1. Test Chamber Environment During Testing of the T-111 Rankine System Corrosion Test Loop.

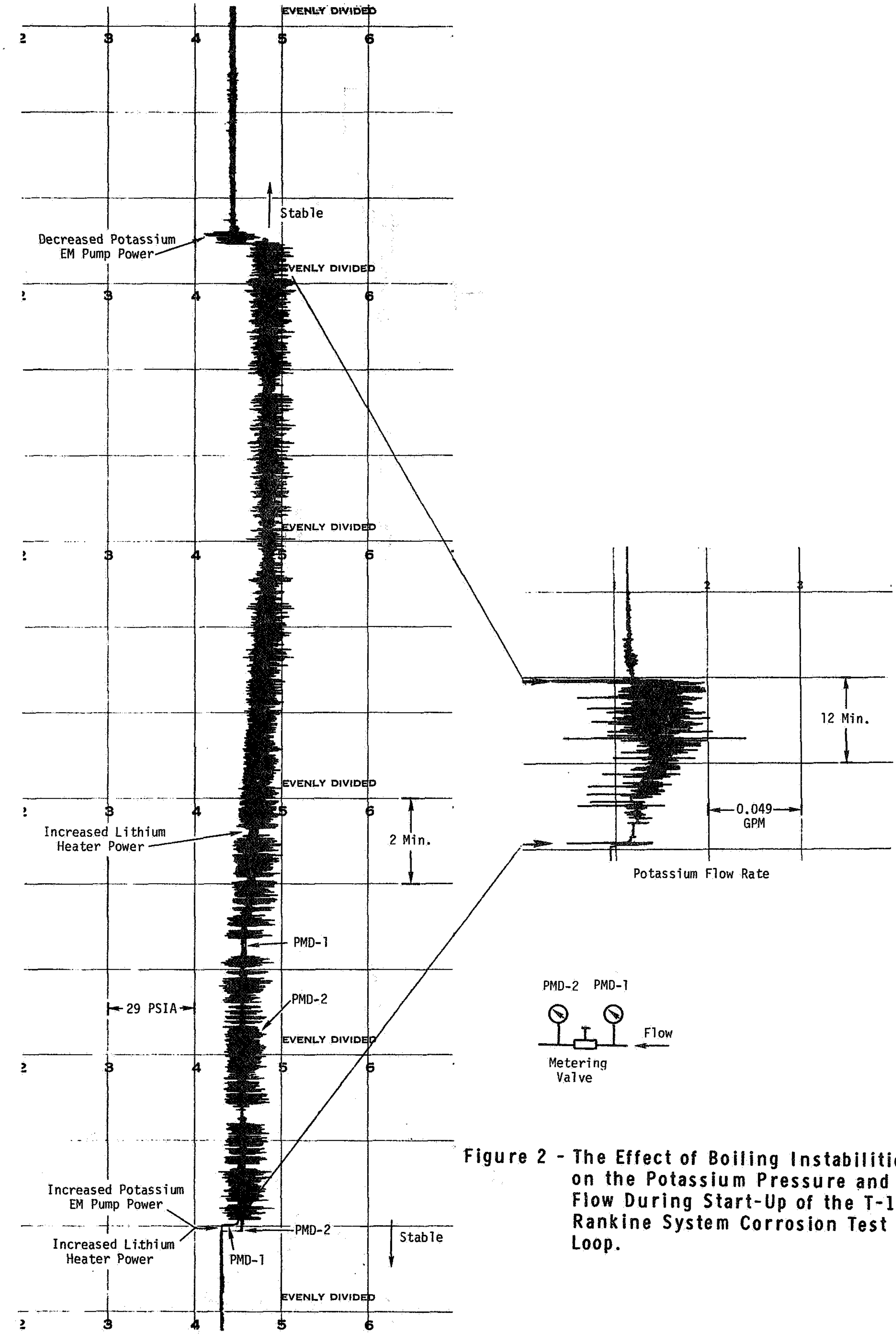

Figure 2 - The Effect of Boiling Instabilities on the Potassium Pressure and Flow During Start-Up of the T-111 Rankine System Corrosion Test Loop.

The primary loop temperature, secondary flow rate and preheater temperature were increased until the design conditions were met as described in the test plan,[3] namely:

Boiling temperature	2050° ± 25°F
Superheat temperature	2150° ± 10°F
Condensing temperature	1400° ± 25°F
Potassium flow rate -	35 lb/hr ± 5 lb/hr

The T-111 Rankine System Corrosion Test Loop began logging hours at 1630 hours on January 25, 1969.

B. T-111 RANKINE SYSTEM CORROSION TEST LOOP OPERATION

1. Operational Surveillance

On March 8, 1969 the T-111 Corrosion Test Loop completed 1000 hours of operation. As a result of the stable and trouble-free operation of the loop during this period, constant surveillance appeared to be less of a necessity than originally anticipated. Furthermore, adjustments made during this testing period were limited predominantly to minor adjustments to the lithium heater to compensate for line voltage fluctuations not compensated for by the voltage stabilizer.

The effect of these fluctuations on the lithium boiler inlet temperature were examined during the period March 11, 1969 to March 17, 1969 with no adjustments being made from 1600 hours to 0800 hours. It was found that anticipatory adjustments to the lithium heater power made by daytime shift operators could result in maintaining the lithium boiler inlet temperature within ± 25°F.

On March 22, 1969 loop operation was reduced to the daytime shift with unattended operation from 1600 hours to 0800 hours. No difficulties were encountered in maintaining stable loop operation, and the lithium boiler inlet temperature was easily maintained within a ± 25°F band as indicated in the data shown in Figure 3. The potassium vapor temperature

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[3] Advanced Refractory Alloy Corrosion Loop Program, Test Plan for T-111 Rankine System Corrosion Test Loop, Page 34.

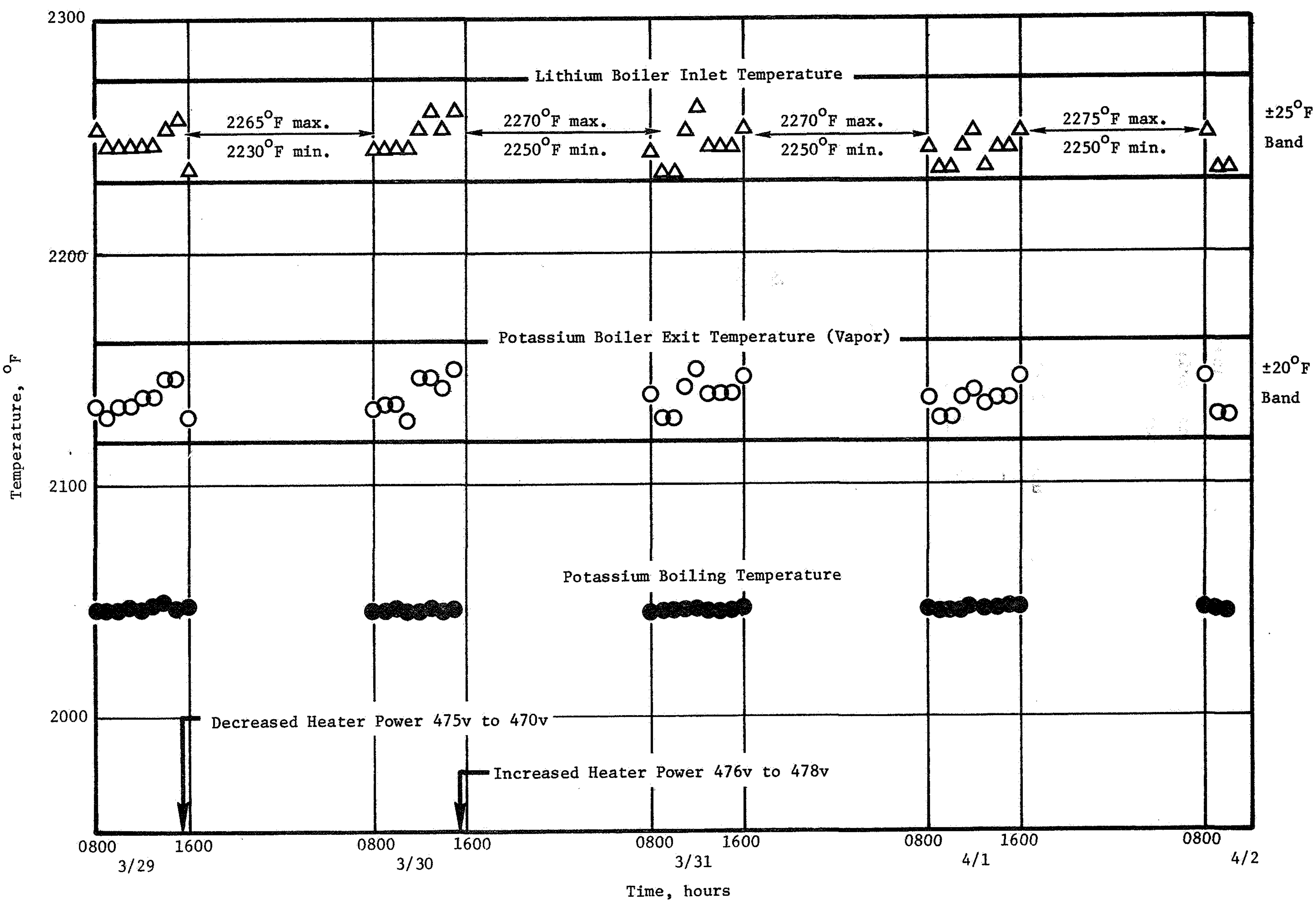


Figure 3. Temperatures of Interest Recorded During Operation of the T-111 Rankine System Corrosion Test Loop on the Daytime Shift Only With Unattended Operation Between 1600 Hours and 0800 Hours.

at the exit of the boiler was maintained within a ± 20°F band. The boiling temperature, which is determined by the boiler inlet pressure, was maintained within ± 2°F. This further indicates the stability of the inlet pressure and concomitant boiler outlet pressure, of prime interest in turbine operation.

Considering that the temperature measurements in millivolts are read to the nearest 0.05 mv, the plot of the millivolt readings vs time shown in Figure 4 indicates the measured values fall within a ± 1% band.

On April 10, 1969 continuous surveillance of the loop was restored and will be maintained throughout the 10,000 hour test period. With continuous surveillance the lithium boiler inlet temperature can be maintained within a ± 15°F band by adjustments to the lithium heater power when required as previously described.

2. Loop Temperatures

On April 19, 1969 the T-111 Corrosion Loop completed 2000 hours of operation. The loop temperatures recorded at that time are shown in Figure 5 and temperatures of major interest are shown on the loop schematic in Figure 6. The performance of the loop has been excellent in that control adjustments have been limited to minor changes in the power input to the lithium heater to compensate for small line voltage changes not compensated for by the voltage stabilizer. A comparison of the data obtained at 1000 hours with the 2000 hour data shown in Table I further indicates the stability of the loop's performance.

3. Boiler Conditions

The lithium temperature profile in the boiler and the calculated potassium quality and temperature as a function of boiler length are given in Figure 7. The calculated qualities indicated are based on thermal calculations involving potassium flow, potassium boiler inlet temperature, lithium flow and the drop in the measured lithium temperatures as a function of boiler length. Calculations indicate approximately 100% quality vapor is attained at the exit of the plug section, 18 inches from the boiler inlet. In the remaining 195 inches the vapor is superheated to 2147°F. The 135°F of superheat is the difference between the

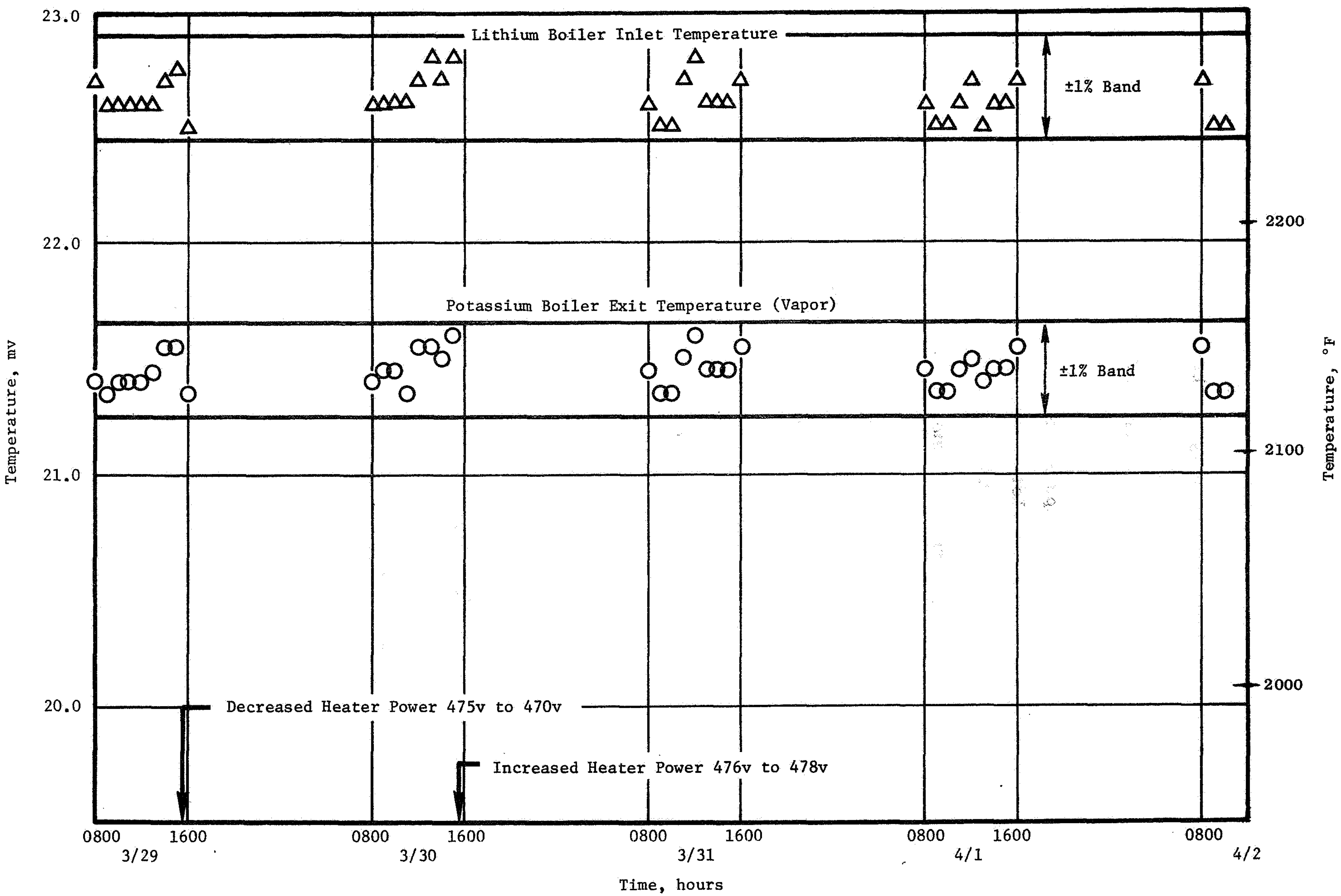


Figure 4. Temperatures of Interest Recorded During Operation of the T-111 Rankine System Corrosion Test Loop on the Daytime Shift Only With Unattended Operation Between 1600 hours and 0800 hours.

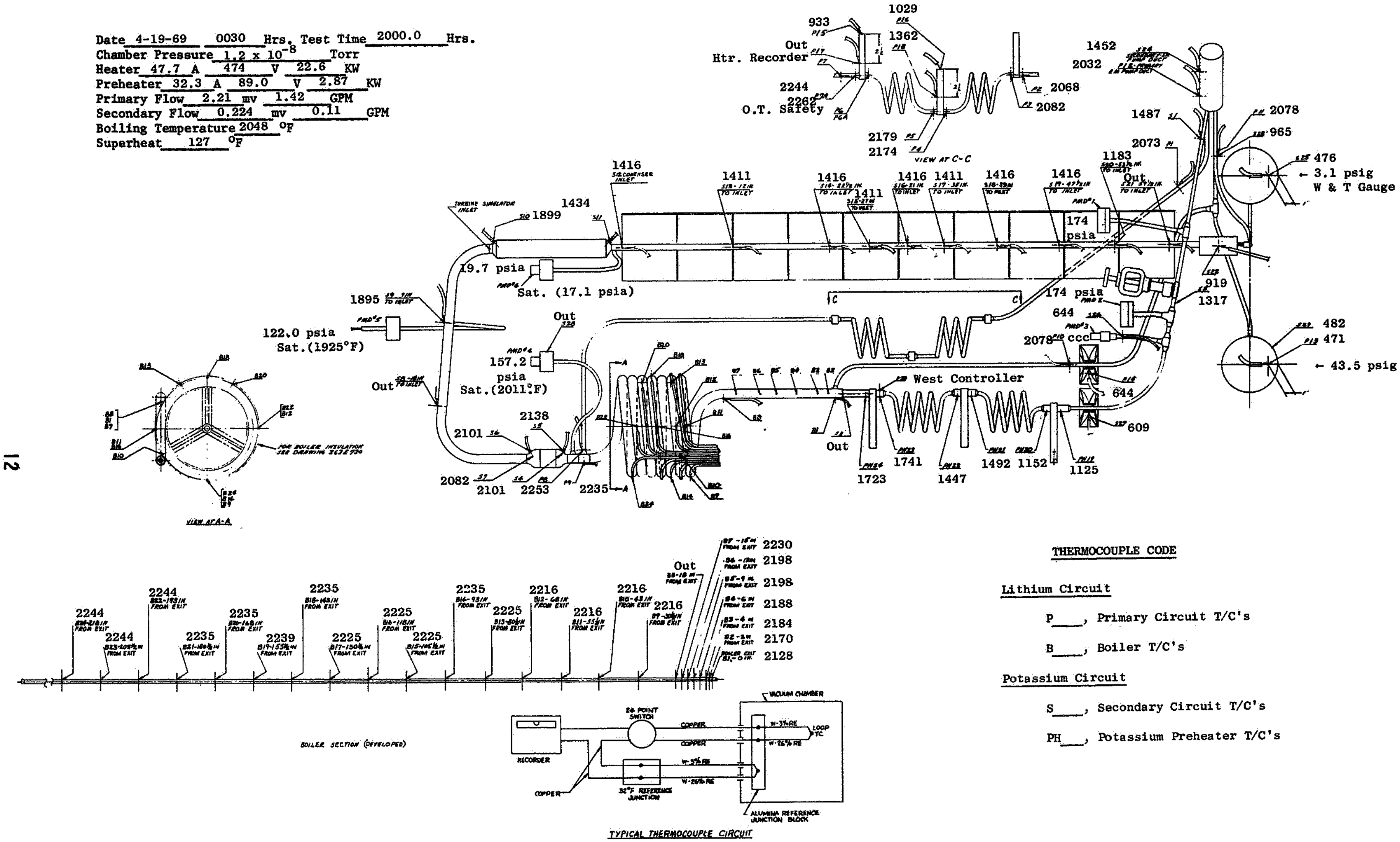


Figure 5. T-111 Rankine System Corrosion Test Loop Temperatures at 2000 Hours.

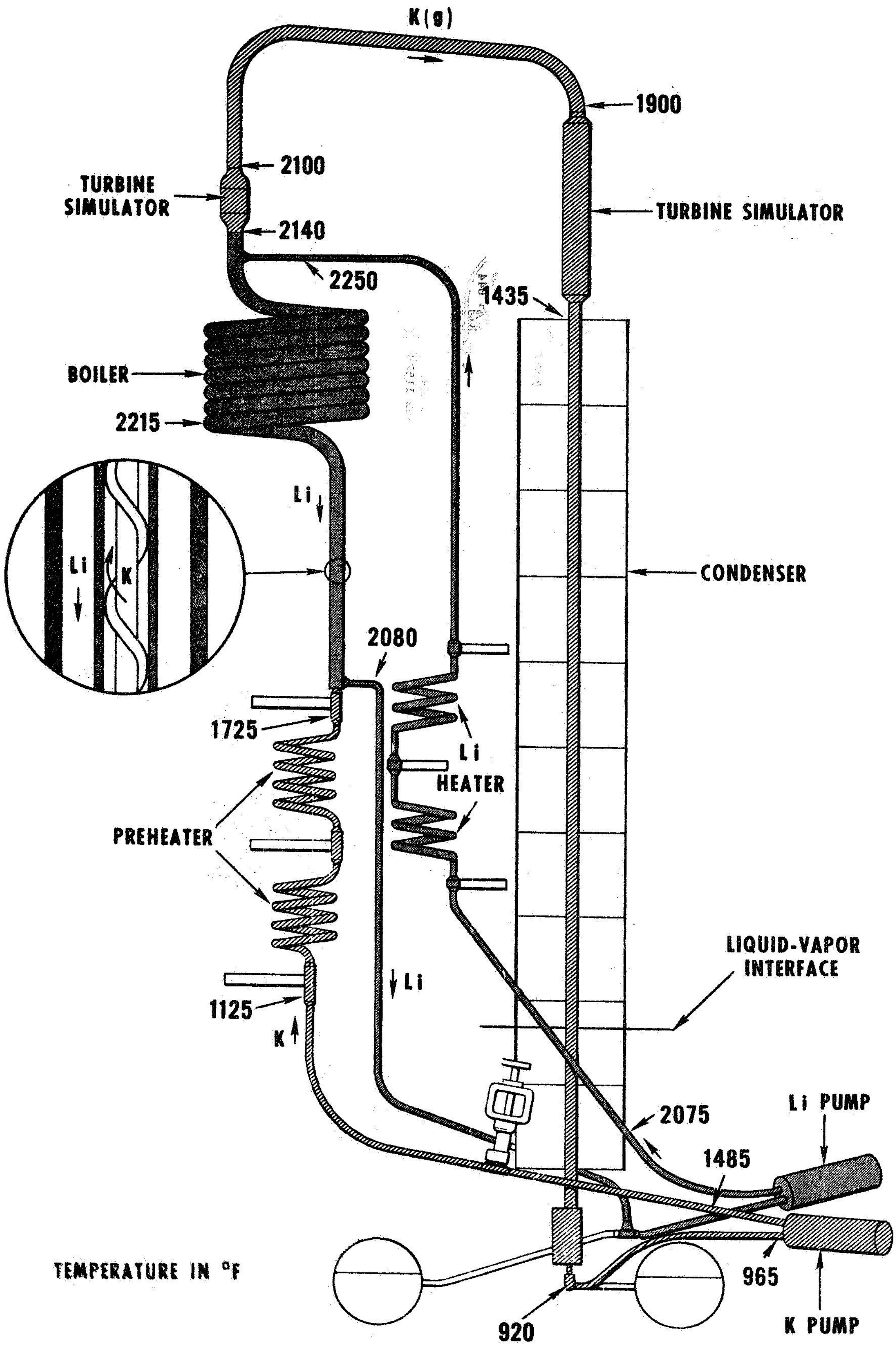
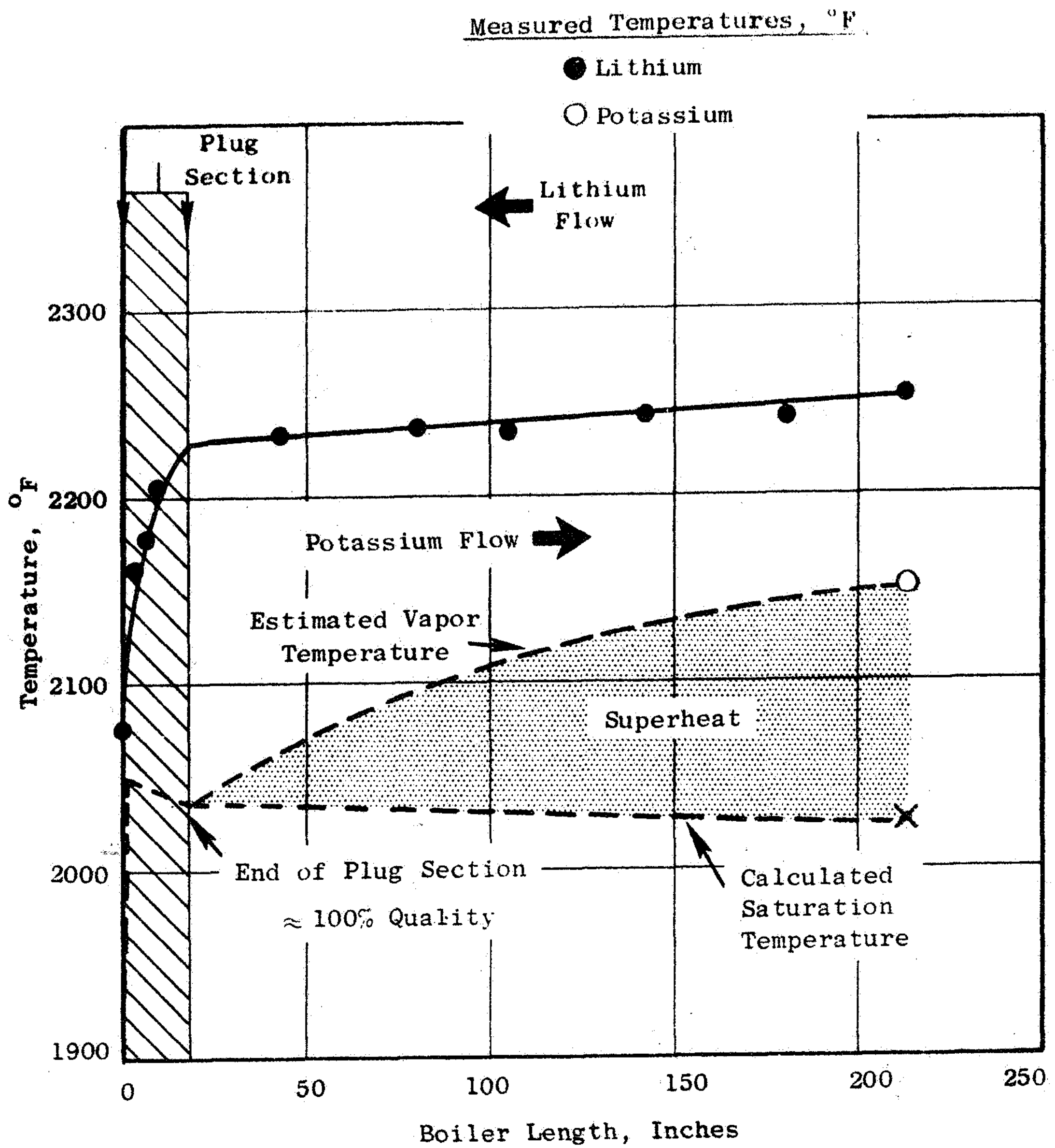


Figure 6. T-111 Corrosion Test Loop Operating Temperatures - 2000 Hours.



Boiler Conditions

Net Heat Transfer - 8.65 KW

Lithium
- Flow Rate, 205 lbs/hr
- Inlet Temp., 2253°F
- Outlet Temp., 2078°F

Potassium
- Flow Rate, 36 lbs/hr
- Inlet Temp., 1723°F
- Outlet Temp., 2147°F
- Inlet Pressure, 174 psia
- Outlet Pressure, 157 psia

Boiler Components

Lithium Tube, OD - 1.0-Inch
ID - 0.8-Inch

Potassium Tube, OD - 0.375-Inch
ID - 0.250-Inch

Plug, 18-Inch Long, Formed by Wrapping a 0.06 Inch Diameter Wire on a 1-Inch Pitch Helix on a 0.125-Inch Diameter Center Rod.

Figure 7. T-111 Rankine System Corrosion Test Loop Boiler Conditions After 1000 Hours Operation.

TABLE I

T-111 RANKINE SYSTEM CORROSION TEST LOOP PERFORMANCE

Date	3-8-69	4-19-69
Test Hours	1000	2000
Lithium Flow Rate	205 lbs/hr	207 lbs/hr
Lithium Temp., In	2253°F*	2253°F*
Lithium Temp., Out	2078°F	2078°F
Lithium ΔT	175°F	175°F
Potassium Flow Rate	36 lbs/hr	37 lbs/hr
Plug Boiling Temperature	2048°F	2048°F
Boiler Exit Vapor Temp.	2147°F	2138°F
Boiler Exit Saturation Temp.	2012°F	2011°F
Potassium Vapor Superheat	135°F	127°F
Condensing Temperature	1416°F	1416°F
Potassium Heat Input		
1. Preheat	2280 Btu/hr	2340 Btu/hr
2. Heat of Vaporization	26,300 Btu/hr	26,950 Btu/hr
3. Superheat	1040 Btu/hr	947 Btu/hr
TOTAL	29,620 Btu/hr	30,237 Btu/hr
Total Power to Lithium Heater	13.2 kw	13.7 kw
Total Power to Potassium	8.7 kw	8.9 kw
Net Heat Loss	4.5 kw	4.8 kw

* The lithium boiler inlet temperature is maintained within ± 15°F by appropriate adjustments to the lithium heater power.

measured temperature of the potassium vapor at the boiler exit, 2147°F, and the saturation temperature, 2012°F, as determined by the boiler exit pressure, 158 psia.

4. Boiling Stability

The pressure and flow traces shown in Figure 8 indicate the stability of the boiling in the loop. Pressure fluctuations noted on the Taylor gauges are less than 1 psia.

5. Test Chamber Environment - Partial Pressure Analysis

The chamber pressure and partial pressures of the various gaseous species in the test chamber during the period of loop operation up to 2000 hours are shown in Figure 1. The total pressure (sum of partial pressures) is consistent with the ion gauge reading, even though it is nearly a factor of two greater. The reason for this is that the major specie is hydrogen which has a rather low ionization efficiency, the ion gauge sensitivity relative to nitrogen being only 0.42.

At the start of loop operation at design conditions, the ion gauge reading was 1×10^{-6} torr, but dropped rapidly reaching the 10^{-8} torr range in less than 100 hours. Throughout the 2000 hour test period, 90 to 95% of the residual gas in the chamber was hydrogen. The source of this gas is probably outgassing of heated metal parts, either the loop itself or the supporting structure. In either case, the hydrogen partial pressure, and thus the total pressure, can be expected to slowly decrease throughout the period of future loop operation. The fact that the N_2 and CO, Ar, and O_2 concentrations are so low indicates the absence of any appreciable leakage in the system.

It is of interest to compare the residual gas composition in the present test with that obtained under similar conditions in the previous Cb-1Zr Corrosion Rankine System Loop Test.[4] For the Cb-1Zr loop after 1000 hours of loop operation, the total pressure was about 4×10^{-8} torr with major species N_2 + CO, Ar, and H_2 in approximately equal proportions. For the T-111 loop after 1000 hours, the total pressure was about 4×10^{-8}

[4] Hoffman, E. E. and Holowach, J., Cb-1Zr Rankine System Corrosion Test Loop, Potassium Corrosion Test Loop Development Topical Report No. 7, R66SD3016, General Electric Company, Cincinnati, Ohio, May 1, 1968.

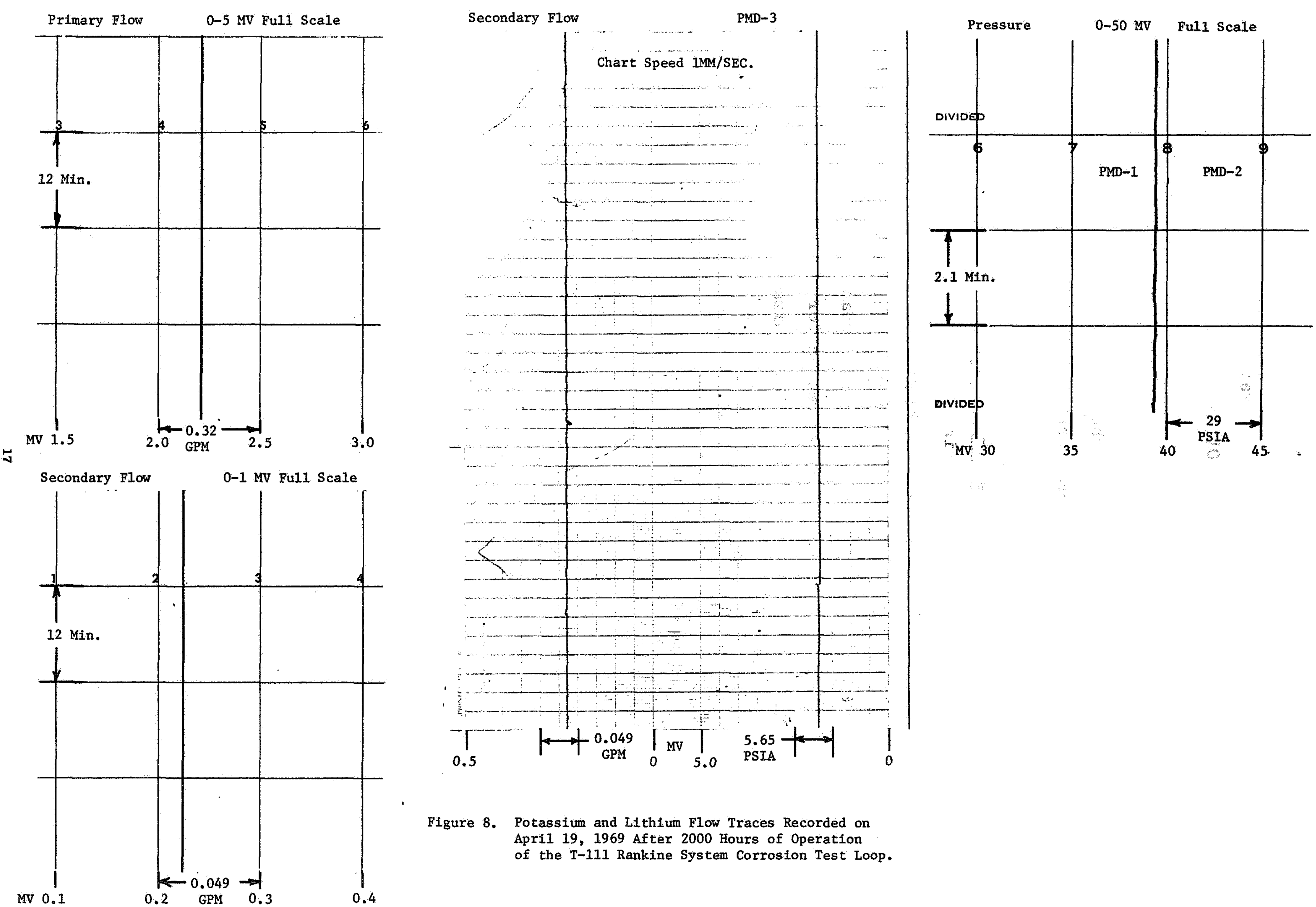


Figure 8. Potassium and Lithium Flow Traces Recorded on April 19, 1969 After 2000 Hours of Operation of the T-111 Rankine System Corrosion Test Loop.

torr with major specie H_2. This comparison thus shows that the same total pressure was obtained in both tests, after 1000 hours, and it indicates that much more hydrogen outgassing occurs in the present T-111 loop test, while the oxygen bearing gases were higher in the Cb-1Zr loop test.

C. ADVANCED TANTALUM ALLOY CAPSULE TESTS

Testing of two ASTAR 811C and one ASTAR 811CN lithium thermal convection capsules continues. As of April 15, 1969, over 4200 hours of testing had been completed. The chamber pressure at that time was 5×10^{-9} torr. An analysis of the temperature distribution in the capsules is being performed to calculate the lithium flow.

D. 2600°F LITHIUM LOOP

A modification of the 2600°F Lithium Loop is anticipated which will lower the operating temperature to 1900°F and incorporate new fuel specimens in the specimen test section.

IV. FUTURE PLANS

A. Continue operation of the T-111 Rankine System Corrosion Test Loop.

B. Complete 5000 hours of testing the advanced tantalum alloy capsules and initiate posttest evaluation.

PUBLISHED REPORTS

Quarterly Progress	For Quarter Ending
Report No. 1 (NASA-CR-54477)	July 15, 1965
Report No. 2 (NASA-CR-54845)	October 15, 1965
Report No. 3 (NASA-CR-54911)	January 15, 1966
Report No. 4 (NASA-CR-72029)	April 15, 1966
Report No. 5 (NASA-CR-72057)	July 15, 1966
Report No. 6 (NASA-CR-72177)	October 15, 1966
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Report No. 10 (NASA-CR-72352)	October 15, 1967
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Los Alamos Scientific Laboratory
University of California
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